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FIFTH CADMAN MEMORIAL LECTURE*

OIL AND EDUCATION

By THE RT. HON. LORD GODBER OF MAYFIELD†

THE occasion of this address is two-fold. First, it gives the Cadman Medallist an opportunity to acknowledge the high honour conferred upon him. This I can do with all gladness and sincerity; for what can please a man more than a distinction such as this, voted by fellow members of the same industry as that in which he has spent his whole life? He feels that, if anyone knows him, they do. So much the greater, then, is his appreciation of this mark of esteem.

The second aspect of the occasion is this. In accepting the Medal, there is no one of my generation who could do so without a consciousness of the achievements of the man whose name it bears—John Cadman. A number of us here will have close personal memories of him. By some standards, ours is a young industry, but thanks to Cadman and others of his stamp it has reached maturity at an early age, and with this maturity (I am proud to say) it has achieved the respect of the world.

THE RIGHT HONOURABLE LORD GODBER OF MAYFIELD, CADMAN MEDALLIST 1957

What Cadman brought to the industry was not only his intellectual gifts and a deep understanding of his fellow men, but a particularly wide experience of the various fields in which these may be applied.

After taking his degrees at the Durham College of Science he entered the coal mining industry. From there he became one of H.M. Inspectors of Mines, and some years later went to organize the Mines and Petroleum Department in Trinidad. In 1908 he returned to the academic scene on his appointment to the Professorship of Mining in Birmingham University. There, he established the Department of Petroleum Technology and remained until 1920.

"Remained" is perhaps the wrong word, for he was never in one place for long. In 1913 he was chosen by the Admiralty as one of the technical members of the Commission to visit the Persian oilfields and report on whether or not they could provide adequate supplies for the Navy. After this, other Government work followed; in 1917 he became Director of the Petroleum Executive and subsequently Chairman of the Allied Petroleum Council. In 1921 he ceased his Government service and devoted his principal energies to the oil industry. On his great contribution to the development and prosperity of the Iraq Petroleum Company and the Anglo-Iranian Oil Company (of both of which he was Chairman for many years) it is not, perhaps, for me to elaborate. Let me recall just one thing, however—that with all the preoccupations a Chairman has, Cadman retained to the last a deep concern with education and its intimate relationship with the petroleum industry. I would like to think, therefore, that he would approve the subject I have chosen for my address to-night—"Oil and Education."

. . . . .

"Human history becomes more and more a race between education and catastrophe."

That was said by H. G. Wells in 1920, when the world production of oil was a hundred million tons a year. As you well know, by 1930 it had doubled itself. But the new figure was doubled before 1950, and this record again doubled within five years. Even H. G. Wells could not have foreseen that. Yet he could visualize the main trend of such development

* Delivered in the Lecture Hall of the Royal Institution on 24 October 1957.

† Chairman, "Shell" Transport and Trading Co. Ltd.

and its effect upon the world—hence the words I have quoted.

What Wells foresaw was that scientific and technological progress would soon leave political—and probably moral—progress behind. That danger is still with us: man's power of invention can always outstrip his sense of responsibility. It would be of no use to attempt decreasing the rate of man's inventiveness to suit the laggard. Man himself must be able to keep up with it. In short, then, the problem is, not to curb genius, but to apply the spur to ethics.

In this, industry and business have an inescapable responsibility; and I suggest that we must willingly accept the obligations which come hard on the heels of all important industrial development.

No big business to-day can afford to ignore the social, political, or ethical factors of the country in which it operates. How much more responsibility devolves, therefore, on companies with worldwide interests who are in a position to view international development, in all its many phases, as a whole.

Such are the oil companies—members of a technological industry, whose remarkable expansion is due most largely to the harnessing of scientific skills and knowledge.

If, instead of oil, we sold safety pins, we might like to know if a foreign Government intended putting a tariff on them. But this, plus a little market research, would be almost all the knowledge we would require. In the oil industry, however, we are faced with a different story. We explore, drill, produce, and process. We transport and we trade. We trade in scores of countries, hundreds of products, to an extent where oil is inextricably mixed with the life of the world. It has made the world smaller. It is woven into the pattern of every country, and wherever we operate we must take our share of responsibility, remembering that industrialization introduces possibilities for evil as well as good in the sociological development of a country.

It is very much our concern, therefore, that the moral welfare of the country is not hindered by its technological progress, to which we ourselves will probably have been notable contributors. Such unilateral progress must not be allowed to impair social coherence and moral stability.

In general terms the problem is the same all over the world, but in each country it has reached a different stage of development. Some countries are now facing the industrial revolution that came to us in Britain more than 150 years ago. In South-East Asia, in Central Africa, and South America towns are sucking in the rural population, as, did Manchester, Leeds, Bradford, and Birmingham, in England, early in the last century. Yet what has taken 150 years for us to assimilate, is bringing material prosperity to some countries in less than one-tenth the time; so rapid is the rate of technological progress.

The future of any of these lands must be based on raising that standard of living through this technological development. But technologists are in short supply, and even if there were sufficient numbers, technology alone is not enough. Unless one is careful it leads to the inward-turning spiral of specialization, which goes deeper and deeper into less and less.

Men of wide experience and broad vision are needed, who can value the specialist but relate him to the whole. Such men can be produced only by education, the complete and generous education which Milton described as " that which fits a man to perform justly, skilfully and magnanimously all the offices, both private and public, at peace and in war."

Too often in a country's history it is the educational services that lag behind. After all, you cannot get good education without good teachers and you cannot get good teachers without good education; progress has to be slow. Furthermore, once the system has been set it is difficult to change its pattern to meet a sudden need—a need which can appear as suddenly as oil. It takes time to orientate schools to produce what is required; and until this can be accomplished the requirements must be met from outside.

I would like to give you an example of this. It is a quotation from an independent investigation carried out within the last decade in an area which happens to produce oil. It is far from being a primitive country if we judge it by the contribution it has made to world civilization; but even here the pattern of education is scarcely in tune with the requirements of this technical age. Allow me to read you an excerpt from the report, which is dated 1949:

" All of the curricula currently in force (it says) are rigid, formal, authoritarian, crowded, and in varying degrees unsuited to modern industrial and agricultural society. They make no allowance whatsoever for variations of needs between individuals, regions, individual schools, or between the fluctuating demand of the labour market. . . . All curricula are highly formal, even academic. They are designed to pour knowledge and information into the student. A few examples are pertinent. A mechanical engineer is hardly educated if he can describe in detail the mathematical formula for calculating the stress on a beam, but cannot recognize the instruments by which the variables for his formula must be measured. A secondary school student of biology is hardly educated if he can name the bones of the skeleton, the muscles of the body, and describe the functions of the several internal organs, but has never dissected a fish or a frog, and systematically and in ignorance violates the basic rules of hygiene which should be the result of his study. An elementary school child is hardly educated on moral grounds if he can reproduce in sing-song a phonetic rendition of religious text, yet neither he nor his teacher know the meaning of a single word. . . .

" Finally, the existing curricula are demonstrably unsuited to modern life. They have failed to produce a sufficient number of the type of citizens and technicians needed, and they have produced a very large number of discontented, badly-adjusted, unproductive graduates who are unequipped to meet the needs and opportunities of the times."

There is not much in this, I think you'll agree, that helps to give dignity and status to those who work with their hands, and the men who carry spanners; not much to bridge the rift between the clerk and artisan.

Let me give you another short quotation (this time from Maurice Zinkin's *Development for Free Asia*):

"The importance of religion combined with the lack until recently of scientific knowledge applicable to Asian agriculture, produced an educational system with quite one-sided emphasis on literary rather than scientific knowledge, on sitting at a desk rather than on using one's hands, on theology and the arts rather than on the wants of every day. Such an educational system can produce Chinese painting and Indian philosophy, just as the similar system of mediæval Europe produced Salisbury Cathedral and St Thomas Aquinas. It is not adapted to the production of fitters and chemical engineers. In addition, there is one difference between modern Asia and mediæval Europe which is severely to Asia's disadvantage. In mediæval Europe the free cities protected enterprise, gave an honoured position to the successful businessman, and obtained from their businessmen in return a strong social conscience. Asia has never had free cities, and its great States have always overtaxed, always given too much importance and too much power to the State servant. Its businessmen in consequence all too often have the low standards of their too low position."

In a fast developing country—especially one where entirely new industries and ways of thought have been introduced—there is bound to be competition for priority among projects of national importance. It is natural, too, that Governments should have some regard for their relative popular appeal. Technical schools, for example, cost just as much as universities, but somehow they don't appear to count for as much when it comes to national prestige, and, of course, it takes longer for their good to become apparent. Similarly, a plan to harness the brain-power of the country is less spectacular than a hydro-electric scheme; the Tennessee Dam commands our awe while the ordinary human mind is taken for granted.

In this country a large sum of money is spent—and justly spent—on educational psychologists and psychiatric work investigating the out-of-the-ordinary, the mentally deficient, the juvenile delinquent, and so on. This is important work. But one cannot help wondering if a similar amount of money, spent for the same purpose among perfectly normal young people, might not increase the effectiveness of our teaching, do more to foster creativity, and inculcate moral and political responsibility in those upon whom the future so urgently depends. I would like to see *all* helped; for *all* can benefit.

There is, to-day, a tendency to put things in pigeon holes, which although it makes a place look tidy, does not always enable one to study inter-relationship, how things overlap or are inter-dependent.

An age does not throw up *only* scientists or *only* painters, *only* writers or *only* industrialists. They go together. We are rather apt to forget the ancient technologists of the Far East until we are suddenly confronted with, let us say, the Chinese seismoscope in the Science Museum dated A.D. 132. China, Mesopotamia, Egypt, Greece, and Rome have all produced a flowering of general accomplishment: in Europe the Renaissance is a more recent example of this. It produced great painters and poets we know, but do not let us forget the explorers and the sailors, or the merchants and the bankers.

Parallel with the great technological advances of to-day is a new spirit in literature and the arts. We have the ability to create poetry, sculpture, and symphonies, as well as earth satellites and world markets. We want men of science in every country in which we operate, but they should also have an appreciation of the arts, just as the arts men who are needed must have a sympathetic understanding of science. Such men are essential to each country and also essential to our business. And when I say we need such men, I speak not merely for the company of which I am a Chairman, but for industry as a whole, and even the world. For to-day, business is not merely buying or selling. It is analysing cause, deducing effect, using foresight, exercising judgment, taking responsibility—in short, putting to use imagination and those other of the higher faculties which are awakened by a broad and liberal education.

Education—and please don't think that by education I mean vocational training—broadly has two ends: to produce the right men for the right job, and to create in all people an understanding that will enable the right man to do the right job most effectively.

In the oil industry the right men and the right jobs vary from country to country, and so do the difficulties which have to be overcome in persuading the nations to realize the importance of those jobs. But, generally speaking, the obstacles to our industrial progress are also the obstacles to national progress, for our prosperity is identified completely with the prosperity of those countries in which we work.

This being so, the industry as a whole, and the individual companies in particular, have come to realize that in each country in which we work we have also a part to play in the fostering and development of education. As private entities with limited resources available to this end, we should not and do not wish to compete, still less to conflict, with the policy and programmes of the local education authority. What we have done in a number of countries is to introduce an entirely new educational requirement—one that no government can meet in a hurry. It is natural, then, that governments should look to us to supplement and stimulate thought in new directions, to direct attention to neglected fields, to prime a pump that will not otherwise deliver a required flow, unblock a channel, or cut a new one into a parched field.

As I have said, the problem differs from country to country, so therefore do the points at which it is possible for us to apply the stimulus or assistance. Let me give you a few examples, not only from my own experience but from associates and competitors.

In Australia, New Zealand, Canada, and South Africa the standard of education is high. Some years ago, however, it seemed that the higher technological education at the universities there would benefit if those who taught and researched in them had been able to complete their own advanced studies among the best brains in their particular fields working at British universities. Commonwealth Research Fellowships were, therefore, financed by one group of oil companies, whereby two graduates from each country came annually to the U.K. to complete their Ph.D. at the British university of their choice.

More recently in Australia and New Zealand it looked as if the university arts course had been too narrowly regarded as a vocational training, and its value as an intellectual preparation for a business career insufficiently appreciated. And so annual awards were instituted to enable arts graduates prepared to make their career in business to spend a mind-broadening year reading for a diploma at Oxford or Cambridge.

In this country, as in North America, the Appointments of Placement Office is a normal and valued adjunct to the university faculties. Where the system does not exist there can be much wastage and frustation through graduates failing to find their right employment except by a progress of personal trial and error. This is particularly true in countries where industry is rapidly expanding and diversifying itself. With a view to remedying such a local gap a vocational guidance and employment office at one university has received financial backing from an oil company for the past five years.

In some countries the universities, whether private or national, receive sufficient funds for buildings and equipment, but are starved of books, and particularly of up-to-date reference and text-books in English. Japan and Colombia are countries, among others, in which universities benefit from assistance to meet this need.

In Great Britain the most serious single "leak" in the educational system, as several of the oil companies have found, is the loss from the grammar schools at sixteen of potential university material drawn away by the immediate wage-earning power of the adolescent in industry. The suggestion has been made * that the State should buy the student's continued attendance at school by competitive allowances. This has understandably been rejected by a Ministry of Education which cannot see its way to meeting even the full cost of maintenance at school, estimated to-day for the seventeen-year-old at £150 per annum. It looks as if industry in this country will increasingly have to take a leaf out of the armed forces book and subsidize to stay at school until eighteen those whom it wishes to come to it with a degree or College of Advanced Technology diploma.

In less developed countries the cost of the secondary schooling and the rewards in industry are lower, but the poverty of parents makes all the greater the temptation to go out and earn. Good boys lose the chance of a professional career, while the universities suffer from the limitation of their choice of entrant. In such cases—West Africa and Malaya are examples—a company will offer not only scholarships to the university but also sixth form bursaries to boys who could not otherwise remain at school to qualify for university entry.

In Sarawak and Brunei, to encourage parental support for the expansion of secondary education from its present small dimensions, the oil industry there has placed at the disposal of the local education authorities scholarship grants for children who will study to take the Senior Cambridge or Higher School Certificate. In Aden fees and travelling costs are provided to encourage children to travel from the Little Aden township to the secondary schools in the main centre.

Children and buildings are two of the necessities of education: another is teachers, and there is scarcely a country where there are enough of them. In Khuzistan the climate is no more attractive to the Persians than to the Europeans, and although the oil company provided schools and there were many children, teachers were reluctant to come from the more equable north to serve in the torrid south. Besides providing the buildings and the equipment, which were handed over to the local authority, the oil company concerned gave 100 per cent hardship grants, that is 100 per cent of the teachers' normal salary, to encourage Persian teachers to teach Persian children in Persian schools in Southern Persia.

Sometimes fashion, social prestige, or a one-sided university curriculum produces too many graduates in one field, not enough in others. This has happened in Brazil in the over-production of civil—and the under-production of mechanical—engineers, so bursaries for civil engineers prepared to take a conversion course to mechanical engineering have lately been established.

In Teheran the law school flourished and produced embryonic lawyers by the hundred every year. Engineering and science requires more costly equipment for an adequate university education, and this was just not available. The oil company operating in that country at the time I am speaking of spent

* *The Times Educational Supplement*, 12.7.57, p. 989.

more than a quarter of a million pounds in providing buildings, equipment, and staff for a Department of Mechanical and Civil Engineering and a Department of Science, and these are now two of the most flourishing departments of a flourishing university. The Iranian Oil Operating Companies are presently awarding twenty-four scholarships for engineering students, to whom practical courses at Abadan are also available during the long vacation.

In Brazil again, as throughout Latin America, economic and social development is hampered by the shortage of trained administrators; support is therefore given to the School of Business Administration lately established in São Paulo. The Administrative Staff College at Henley, and its latest offspring recently established outside Melbourne, received the support of the industry right from the start.

Where local universities exist it is (I think) common policy to support and encourage them, in the belief that, in general, it is more profitable for a young man where possible to complete his first degree in his own cultural environment rather than in surroundings wholly foreign to him. In some countries, however, the university places are either as yet so restricted, or the facilities for technological training so limited that the industrial and economic development of the countries makes it necessary to send many students overseas for their first degree. In such countries several companies have found it expedient to offer scholarships or bursaries to the appropriate foreign university, generally in Britain or North America. A striking example is Venezuela, from which country there are at this moment seventy Venezuelans, who, through one company, are studying as scholars in other South American, North American, and British universities and technical colleges. Whilst in Britain alone there are at this very moment more than 200 Iraqis studying in various advanced educational establishments, and financed by the oil company concerned.

Many of the senior oil men now in Persia have profited by the association between Lord Cadman's oil company and his old University—Birmingham—which in the 1930s, and immediately after the last world war produced eight to ten Persian technologists of high quality every year, whilst similar numbers qualified via technical colleges.

Through oil Trinidad, Malaya, Thailand, and West Africa, among others, have been able to send scholars to England, notably to the College of Technology, Loughborough, where they receive an extremely practical engineering diploma course and where there are to-day forty-one scholars from six countries sponsored by one group of companies. For such scholars studying abroad there is in each country a liaison officer who keeps in touch with them, assists them to find suitable vacation experience or employment, and to whom they can turn in difficulty.

In many countries, as I have already suggested, the most pressing need is not so much for graduates as for more and more technicians at the intermediate level, trained in the supervision and direction of on-the-spot construction, and of artisans skilled in the specialized techniques upon which such developments depend. The establishment of technical colleges is therefore assisted and encouraged by gifts of equipment and, in some cases, the donation of a wing or building devoted to a particular technique. Cases where in recent years such assistance has been given on a substantial scale include the technical colleges in Hong Kong, Nairobi, Mombasa, and Laurenço Marques.

Teaching professionals how to use the latest equipment has not always meant that they learnt oil technology. Sometimes the scientific equipment has been concerned with medicine.

When earlier this year at Cardon in Venezuela the sixty-bed hospital—which had been built by an oil company at a cost of some £850,000—was handed over to the Government, it contained £60,000 worth of equipment, including the very latest diagnostic apparatus, X-ray machinery, and electrocardiographs.

That remote and isolated district would never have had a hospital if it had not been developed as a suitable site for a large oil refinery. At first the nursing staff consisted of four Dutch and twenty English nurses, but gradually local young women—the daughters of fishermen, who had never seen a hospital—were trained in the nursing profession.

Here the doctors had to be Venezuelan, nevertheless a number of the specialists and surgeons made visits to this country to gain further experience in the latest techniques of medical practice.

Across the world in Persia, medical training took a different form. In Abadan Persian doctors were invited to work alongside British doctors, learning new techniques and using apparatus—which was often unique—in their own country.

In this magnificent hospital, too, nurses and orderlies were trained in discipline and taught the importance of hygiene.

Gradually the number of Persians increased, and what was once a British hospital, with a sprinkling of Persians, has now become a Persian hospital, with a handful of Britons.

In that same town the very advanced Technical College, whose diplomas are accepted in the U.K., was also completely built and financed by the oil company; and the Abadan Institute of Technology is still the major centre of advanced education for the southern half of Persia. In Thailand, where the need is primarily for skilled craftsmen in building and allied trades, the tools and equipment for two craft schools have been provided.

The value of a university education is much enhanced if it is residential, particularly is this so in

As I have said, the problem differs from country to country, so therefore do the points at which it is possible for us to apply the stimulus or assistance. Let me give you a few examples, not only from my own experience but from associates and competitors.

In Australia, New Zealand, Canada, and South Africa the standard of education is high. Some years ago, however, it seemed that the higher technological education at the universities there would benefit if those who taught and researched in them had been able to complete their own advanced studies among the best brains in their particular fields working at British universities. Commonwealth Research Fellowships were, therefore, financed by one group of oil companies, whereby two graduates from each country came annually to the U.K. to complete their Ph.D. at the British university of their choice.

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* *The Times Educational Supplement*, 12.7.57, p. 989.

more than a quarter of a million pounds in providing buildings, equipment, and staff for a Department of Mechanical and Civil Engineering and a Department of Science, and these are now two of the most flourishing departments of a flourishing university. The Iranian Oil Operating Companies are presently awarding twenty-four scholarships for engineering students, to whom practical courses at Abadan are also available during the long vacation.

In Brazil again, as throughout Latin America, economic and social development is hampered by the shortage of trained administrators; support is therefore given to the School of Business Administration lately established in São Paulo. The Administrative Staff College at Henley, and its latest offspring recently established outside Melbourne, received the support of the industry right from the start.

Where local universities exist it is (I think) common policy to support and encourage them, in the belief that, in general, it is more profitable for a young man where possible to complete his first degree in his own cultural environment rather than in surroundings wholly foreign to him. In some countries, however, the university places are either as yet so restricted, or the facilities for technological training so limited that the industrial and economic development of the countries makes it necessary to send many students overseas for their first degree. In such countries several companies have found it expedient to offer scholarships or bursaries to the appropriate foreign university, generally in Britain or North America. A striking example is Venezuela, from which country there are at this moment seventy Venezuelans, who, through one company, are studying as scholars in other South American, North American, and British universities and technical colleges. Whilst in Britain alone there are at this very moment more than 200 Iraqis studying in various advanced educational establishments, and financed by the oil company concerned.

Many of the senior oil men now in Persia have profited by the association between Lord Cadman's oil company and his old University—Birmingham—which in the 1930s, and immediately after the last world war produced eight to ten Persian technologists of high quality every year, whilst similar numbers qualified via technical colleges.

Through oil Trinidad, Malaya, Thailand, and West Africa, among others, have been able to send scholars to England, notably to the College of Technology, Loughborough, where they receive an extremely practical engineering diploma course and where there are to-day forty-one scholars from six countries sponsored by one group of companies. For such scholars studying abroad there is in each country a liaison officer who keeps in touch with them, assists them to find suitable vacation experience or employment, and to whom they can turn in difficulty.

In many countries, as I have already suggested, the most pressing need is not so much for graduates as for more and more technicians at the intermediate level, trained in the supervision and direction of on-the-spot construction, and of artisans skilled in the specialized techniques upon which such developments depend. The establishment of technical colleges is therefore assisted and encouraged by gifts of equipment and, in some cases, the donation of a wing or building devoted to a particular technique. Cases where in recent years such assistance has been given on a substantial scale include the technical colleges in Hong Kong, Nairobi, Mombasa, and Laurenço Marques.

Teaching professionals how to use the latest equipment has not always meant that they learnt oil technology. Sometimes the scientific equipment has been concerned with medicine.

When earlier this year at Cardon in Venezuela the sixty-bed hospital—which had been built by an oil company at a cost of some £850,000—was handed over to the Government, it contained £60,000 worth of equipment, including the very latest diagnostic apparatus, X-ray machinery, and electrocardiographs.

That remote and isolated district would never have had a hospital if it had not been developed as a suitable site for a large oil refinery. At first the nursing staff consisted of four Dutch and twenty English nurses, but gradually local young women—the daughters of fishermen, who had never seen a hospital—were trained in the nursing profession.

Here the doctors had to be Venezuelan, nevertheless a number of the specialists and surgeons made visits to this country to gain further experience in the latest techniques of medical practice.

Across the world in Persia, medical training took a different form. In Abadan Persian doctors were invited to work alongside British doctors, learning new techniques and using apparatus—which was often unique—in their own country.

In this magnificent hospital, too, nurses and orderlies were trained in discipline and taught the importance of hygiene.

Gradually the number of Persians increased, and what was once a British hospital, with a sprinkling of Persians, has now become a Persian hospital, with a handful of Britons.

In that same town the very advanced Technical College, whose diplomas are accepted in the U.K., was also completely built and financed by the oil company; and the Abadan Institute of Technology is still the major centre of advanced education for the southern half of Persia. In Thailand, where the need is primarily for skilled craftsmen in building and allied trades, the tools and equipment for two craft schools have been provided.

The value of a university education is much enhanced if it is residential, particularly is this so in

the case of universities drawing their students from several neighbouring countries. This was emphasized in a recent report of the Sub-Committee on Halls of Residence published on 30 September 1957. This is the reason why one oil company's contribution to The American University of Beirut took the form of a donation for the establishment of residential halls for men and women students.

Much is done to-day by different companies to organize vacation courses—sometimes at refineries—and to promote exchange visits of teaching staff and students between universities in different countries. Much more could still be done with advantage, particularly in the field of enabling university staffs abroad to visit their opposite numbers at British universities, and vice versa. It is also very desirable that teachers of the applied sciences should have seen at first-hand the application of their teachings in so highly technical an industry as our own. Regular visits are arranged for British teaching staff to the oilfields, refineries, and laboratories in Europe; of Australian and New Zealand professors and students to oilfields in Borneo; and, on occasion, financial assistance enables teaching staff from South American and other universities to visit Europe, or guest lecturers to visit these universities.

In the U.S.A. a principal concern of industrialists and of the education authorities is the loss of attraction in teaching, and particularly in teaching the sciences, which has reached such a pass that in half of all American high schools neither physics nor chemistry is taught at all. One contribution to the solution of this problem has been—in addition to graduate and post-graduate scholarships—to organize and pay each year for refresher courses at universities for some sixty teachers willing to bring their own knowledge and teaching methods in these subjects up-to-date.

Turning back now to Great Britain, oil companies, in common with other large industrial concerns, have attempted over the years to prime the pump at various points on the educational pipeline. In the early years of the century it was the expansion of physical chemistry as a field of study at the university which claimed our attention. Between the wars the emphasis shifted to geology and petroleum technology.

Lord Cadman was, as we know, a great educationalist as well as being an oilman, and it was primarily due to his vision, and the money of the oil company with which he was concerned, that the Department of Chemical Engineering and Oil Technology which flourishes in Birmingham University to-day was founded between the two great wars.

After the last war a Chair of Chemical Engineering at Cambridge was established, and similar faculties elsewhere have been endowed because it was apparent that in this field lay the critical deficiency in the industrial potential of post-war Britain. Meanwhile other universities, such as Leeds, Manchester, and Durham, were being helped by other oil concerns. More recently several oil companies participated in the establishment of the Industrial Fund as a contribution towards raising to the same percentage as obtains in the secondary grammar schools the proportion of boys and girls taking science in the public schools.

To-day the industry is reaching out into fields new to us in the attempt to foster science-mindedness in the coming generation, and this problem is being tackled on several fronts. Why, out of ten students at the Teachers' Training Courses, do nine take handicrafts for every one that takes mathematics, when mathematics is the foundation and master-tool of modern technology? Here is a field for investigation which I urged upon Parliament in my maiden speech in the House of Lords. Perhaps the distaste for mathematics can be traced to unimaginative teaching techniques. If so, then the problem may be solved in some degree with a mathematical textbook for use among student teachers in training colleges, a project in which some of us are interested.

It might also be extremely useful to spend some time—and money—in investigating how science and everyday life can be brought more usefully together in the minds of boys and girls before they begin to specialize at school.

In these examples the problems are all variations on the theme of education, but the circumstances vary immensely. We must be careful to work within the existing framework in each country. It is not our business to worry whether schools are in the hands of private individuals or the State, whether they are co-educational or convent—the children are of equal importance. And if those children are well educated they will grow up with a sense of responsibility; then the wealth which we can bring will be used for making a country rich.

The problems may be confined to a town, a county, a province, a region, or a country. But whatever size of territory is involved we must see the problem in world perspective, viewing the picture as a whole. Though we in England may still feel the rift between science and the arts, this has not been apparent in, say, Hong Kong; while in South America they have learnt by our mistakes and arranged curricula so that they don't fall into the same trap.

I have tried in this address, first, to draw the broad outline of oil and education, to establish, as it were, the scale of our responsibilities. Next I attempted to give detailed examples from different companies and different countries. Now let us look at the picture from a chronological point of view and see if there is any trend to be deduced from the pattern. It would be fair to say that in the beginning interest in education was limited to vocational training once a man had joined the industry. But very soon after this it was realized that certain basic

knowledge, acquired before joining the industry, was of great importance. Since the needs of the industry were constantly changing, the emphasis in this knowledge shifted too—at one point it might be from geophysics, perhaps, to chemical engineering. This meant an incursion into education at a specific point for a specific purpose.

Meanwhile there were two streams within the industry which continued to grow. First, the training of employees, which, as the industry has come to realize that the balanced man is the most useful, has broadened out from purely vocational training to something much wider than the narrow application of a technique. In the apprenticeship scheme this stream may lead one out of the industry back into national education for a long or short spell, before training is complete and he rejoins the industry for his career. These are the thick and thin sandwich courses which we all know so well.

The other educational stream within the industry is that which carries the children of employees. This leads out of the industry, and delivers them to a higher form of education either at home or abroad. In fact, often the company school itself is handed over as soon as possible to form part of national education. This is in keeping with an I.L.O. memorandum.

The education of employees' children was studied by the I.L.O. at Los Angeles in 1947 and Geneva in 1948 and 1950. Among the different aspects discussed was one which dealt with the respective responsibilities of government and oil company in the educational field. Many hours were spent in studying this, and many countries had many views. But it was generally agreed that the long-term objective should be to integrate any educational facilities provided by the oil companies with the educational system of the country.

In some places the oil companies may learn something from the national educational system, in others the country may learn something from the oil company, but from the friendly interchange of ideas and knowledge nothing can come but good. It is a practical demonstration of the words engraved around the Cadman Award itself—" Through the light of intelligence to the increase of knowledge."

Now if we analyse the ages at which we have taken interest we find that it has shifted from the employee first to the potential employee, the graduate, then to the undergraduate, and now to those at college—the Colleges of Advanced Technology. This tendency is not confined to the oil industry, it is the result of our technological civilization. All industries are becoming aware of the growing shortage of properly qualified manpower. The Government recognizes it and has said our scientific manpower must be doubled. The tendency to take an interest in education at an increasingly early age must, therefore, continue.

There are, however, signs that industry as a whole is becoming more conscious of its obligations and responsibilities to the community. Only in September last was it announced that a generous reply to the appeal for industry to plough back into colleges and universities some of its technical know-how—I quote the *Manchester Guardian*, 17 September—" has been made by two companies who are collaborating in a piece of management training from which neither company will receive direct benefit."

This may perhaps be the start of a new trend, or it may be an isolated experiment. At least it shows that industry is anxious to help education in Great Britain and is willing to collaborate with the new Colleges of Advanced Technology in trying out something new. And so it should be—all over the world.

An international oil company is, in a way, a sort of United Nations Organization. Not a philanthropic association built on pious hope, but a commercial enterprise with a policy of enlightened self-interest which has slowly and painstakingly built up an international machine which works in the main smoothly and efficiently. Whether or not it may become the prototype of a commercial or industrial UNO in the future is not for me to say. But what I do say is this.

In spite of growing political difficulty, this industrial machine is becoming more and more efficient. Given a sense of responsibility—and as Shaw said, Liberty means Responsibility—its power can be used ethically and normally. It behoves us to look ahead and see that it works in the wider interests of each country of which we are a part.

I have tried to give you some impression of this particular problem and how we are meeting it. Much is still to be done, but we believe we are on the right lines to our own ultimate advantage and to the advantage of national interests wherever this may be.

To end this address I would like to tell a story which perhaps sums up oil and education.

It happened to an oilman who worked with Lord Cadman, and it would, I am sure, have given him great pleasure.

In 1939, whenever a train stopped on the Ahwaz/Teheran Railway, children would rush forward and with outstretched hands beg for *baksheesh*. Ten years later the children were still rushing forward, but they were demanding *mādad*. Pencils were what they cried for instead of pence. The old men in the background nodded their heads in approval, the younger generation would have *savād*—they would be literate, and have knowledge. And above the door of every school in Persia is written a quotation which ends " with knowledge the old heart becomes young."

This is the plea we hear in all the countries to which our operations call us; and I say in no boasting spirit but in all humility that we may be proud of the part we are playing in meeting this cry.

PRESENTATION OF THE CADMAN MEDAL

At the conclusion of the address the chair was taken by the President of the Institute, **The Right Honourable Lord Geddes,** who in presenting the Cadman Medal to Lord Godber, said:

Not only the Institute of Petroleum but the whole of the petroleum industry looks back with gratitude to the service of the late Lord Cadman, who twice was President of the Institute.

In 1946 the then Anglo-Iranian Oil Company established in his memory the Cadman Memorial Fund of which the Institute is Trustee. The purpose of this Fund is to provide a Medal to be awarded at least once every three years to men of any nationality who have made outstanding contributions to the petroleum industry in general, and in particular to petroleum technology or hydrocarbon chemistry, and who have delivered a lecture such as we have just heard.

This is the fifth occasion upon which the Medal has been awarded.

I deem it a great honour that it should fall to me, sir, to thank you for your most interesting address and to award this Medal to you.

On behalf of the Institute of Petroleum and all those present, thank you very much.

After receiving the Medal, to the accompaniment of prolonged applause, **Lord Godber** signed the Book of Honour and expressed his thanks to the Council of the Institute of Petroleum and to his colleagues in the petroleum industry for the great honour which had been bestowed upon him.

COMPATIBILITY OF GREASES *

By R. TOURRET † (Fellow) and A. J. S. BAKER † (Associate Fellow)

INTRODUCTION

THE inadvisable procedure of mixing two or more greases intended for use in rolling-element bearings is a subject which has begun to receive serious attention only in the last year or two. It has, however, been recognized for a much longer period that the effect of such mixing may be to produce a material inferior to either of the constituent greases, and further, that such mixing occurs only too frequently in service. Recently, however, there has been an awakening to the dangers of incompatibility, and two authorities have produced papers on the subject.[1, 2] In recognition of the potential troubles which may be caused by incompatibility, some exploratory work has been carried out at the Admiralty Oil Laboratory.

It has been shown[1, 2] that the mixing of two lubricating greases of different soap bases which may occur in service can result in impaired performance. Greases are said to be incompatible if the physical properties and service performance of their mixtures are poorer than would be expected from consideration of the properties of the individual greases. This is usually interpreted as meaning that the greases are incompatible if a property of the mixture is worse than that of either of the two greases separately.

Most cases of incompatibility so far published arise from mixtures of greases of different soap bases. Instances have occurred[1, 2] when greases of the types of bases shown in Table I were mixed. This list is not exhaustive but is given merely for illustration.

TABLE I

Examples of Incompatibility between Greases of Different Bases

Example	Reference	Base of first grease	Base of second grease	Base of third grease
1	1, 2	Calcium	Sodium	—
2	1	Lithium/calcium	Barium	—
3	1	Calcium	Sodium	Lithium
4	1	Calcium/lead	Sodium/aluminium	Lithium/calcium
5	2	Lithium	Sodium	—
6	2	Barium	Sodium	—
7	2	Lithium	Barium	—
8	2	Lithium	Calcium	—
9	2	Lithium	Silica/aerogel	—

In most cases the trouble became evident when the mixture exhibited undue fluidity and, in extreme cases, was fluid even at room temperatures.

APPARATUS AND TEST PROCEDURE

It was not practicable to test greases for every possibility of incompatibility. Such testing would include every possible mixture of greases, of different thickeners, of different types of formulation, being mixed in every possible proportion and tested at a multitude of temperatures. Tests applied might include every procedure to which a new grease might legitimately be subjected. Mixtures of more than two greases might be examined and the action of new *v.* old grease as a contaminant. Altogether, the problem was too vast to tackle, especially since many of the tests to ascertain service performance occupy 500 or 1000 hours.

Accordingly, the programme attempted was limited in scope. Penetration or dropping point measurements have been shown[2] to be inadequate to determine incompatibility and a mechanical function test has been stated[2] to be necessary. Mechanical performance therefore was assessed in the same ASTM Wheel Bearing Grease Tester (Fig 1) as used earlier,[2] since this test employs a rolling bearing and is completed in the comparatively short period of 6 hours. It was considered reasonable to assume that any signs of incompatibility would be evident in this period.

Details of the apparatus and test procedure are given in ASTM Method D1263–53T. The grease to be tested is placed in an automotive type hub-and-spindle assembly containing two taper-roller bearings, but without the usual grease seals. The assembly is provided with a pulley and electric motor to enable the outer hub to be rotated at the desired speed of 660 rev/min. The rig differs from most test machines, and many service applications, in that the outer races of the bearings rotate whilst the inners are held fixed. Suitable cups and trays are arranged to catch any exuding grease, and at the same time provide convenient weighing receptacles. The whole assembly is contained in a lagged cover having thermostatically controlled electric heating elements to maintain the temperature of the spindle at 104° C, at which temperature the ambient is 113° C. After a 6-hour run at test conditions there should be not more than 10 g leakage of grease or oil and there should be no deposit such as varnish, gum, lacquer, etc., on the bearings. The tracks should not be discoloured or marked.

It was considered worthwhile making some further investigation of structure or consistency changes and the method used to investigate this was the Shell micro-cone penetration method,[3] in which a small metallic 78° cone weighing 58·3 g was substituted

* MS received 3 September 1957.

† Admiralty Oil Laboratory, Brentford.

for the standard 150 g cone of the IP penetrometer and a small container was used instead of the standard worker pot. This permits of much smaller samples than required by the standard IP Method 50/56. The manipulation was the same as in the standard test, but in certain cases this was not possible and the results were then obtained as soon as practicable. The micro-penetration figures obtained after test were determined on samples of grease taken from the bearing. For the purposes of these tests, an arbi-

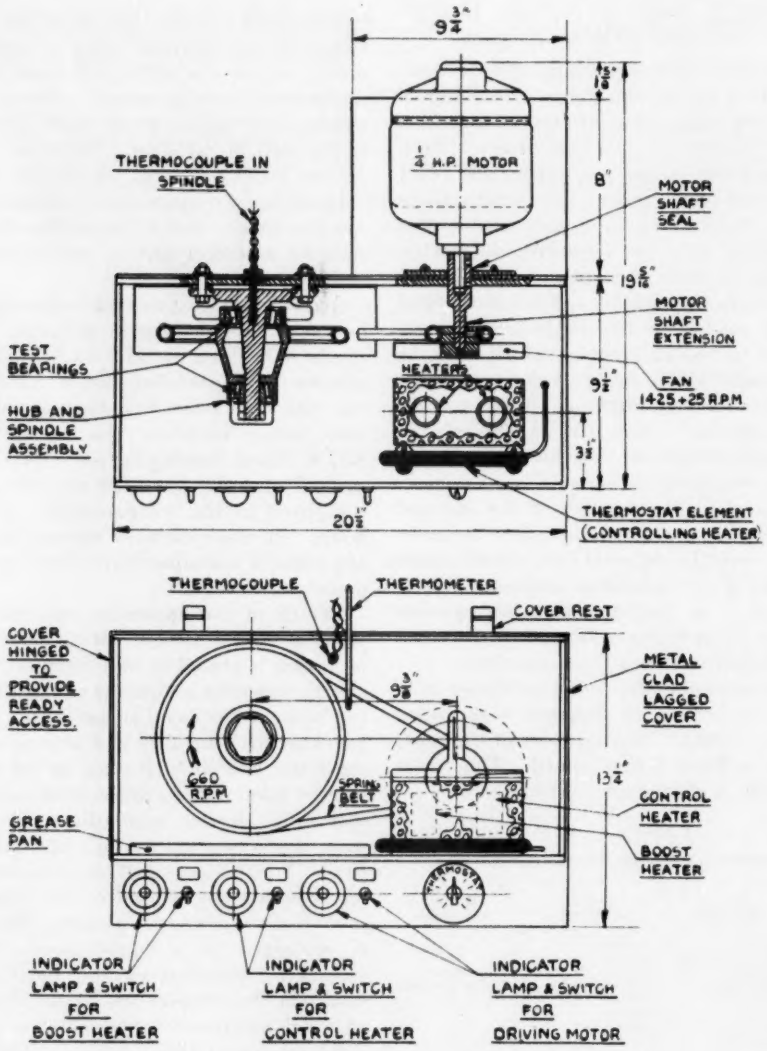

FIG 1

ASTM WHEEL BEARING TEST RIG

method, *i.e.* the cone was allowed to drop into the grease surface during a period of 5 seconds and the penetration was measured in deci-millimetres.

The micro-penetrations of the greases or mixtures thereof, both before and after test, were determined using this micro-cone. The penetration of the grease after test was, as far as possible, determined on the morning following completion of the wheel bearing

trary limit to the change in penetration after test of 25 micro-units was selected for consideration. Greases which exceeded this limit were considered to have failed.

The first tests were made on mixtures which had been merely bulked together by placing one grease on top of another. This procedure was adopted because it seemed to simulate service conditions, in

which a bearing half filled with one type of grease might be filled by an additional supply of another type of grease. However, in course of discussing the test method with other laboratories it became apparent that if they had occasion to make mixtures they did so by carefully spreading the grease out on a flat plate and then spreading the other grease on top, folding, and then re-spreading. This method would serve to mix the greases fairly thoroughly with the minimum amount of working. It would be likely to afford more repeatable results, but these results would be less likely to be applicable to service conditions. Tests on grease mixtures made by this " folding " process were then conducted.

Following this work, tests were also performed on grease mixtures which had been made by deliberately working the greases together for 3000 strokes in a mechanical grease worker. This procedure, which had been used elsewhere,[2] seemed to have the double advantage of simulating service, since greases in service might be mixed together by the moving parts that they were lubricating, and of being likely to give more repeatable results.

RESULTS

Greases A, B, C, and D were used in the first programme. Grease A was a commercial sodium-base grease intended for ball and roller bearings operated at normal ambient temperatures and found to be generally satisfactory in Royal Navy service. Greases B, C, and D were wide-temperature-range XG–271 greases to Specification DTD.783, designed primarily for use in Service aircraft. Grease B was lithium-base, while the other two products were both sodium-base. None of the greases was required to pass the ASTM Wheel Bearing Grease Test.

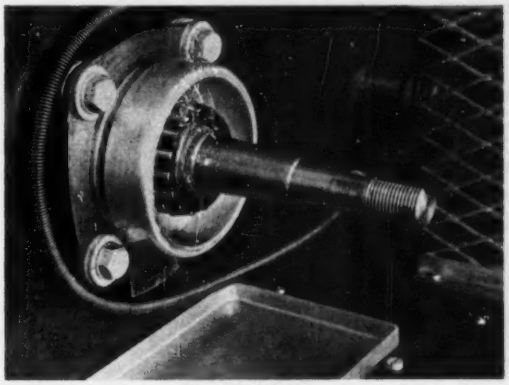

FIG 2
TYPICAL PASS. SHAFT CONDITION

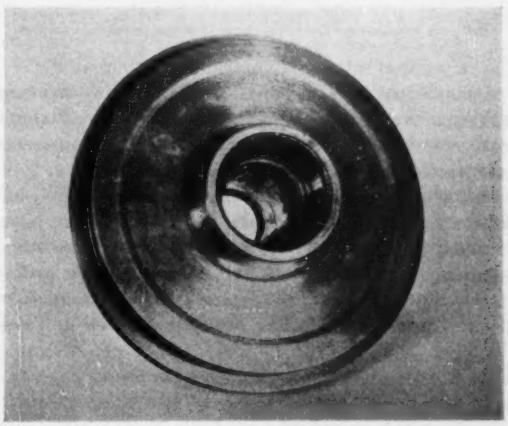

FIG 3
TYPICAL PASS. INNER RACE CONDITION

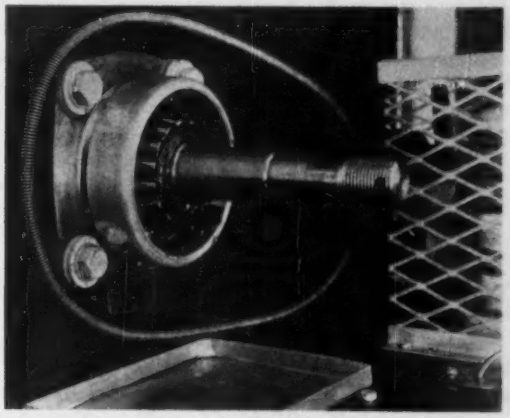

FIG 4
TYPICAL FAIL. SHAFT CONDITION

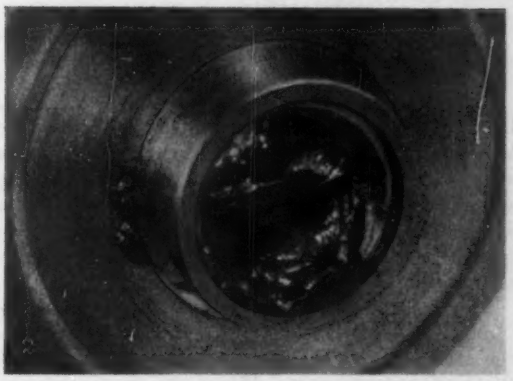

FIG 5
TYPICAL FAIL. INNER RACE CONDITION

In the first programme all tests were performed in duplicate to assess the repeatability of the results obtained. This was done since these were the first tests conducted at A.O.L. on this rig, and a secondary aim of the tests was to establish the repeatability. The leakage results are given in Table II, the results being expressed directly in grams. The greases are marked " pass " or " fail " solely from a consideration of whether the weight of grease which has leaked exceeded 10 g, since none of them gave any deposits. The appearance of a typical pass result is shown in Figs 2 and 3 and a typical fail result in Figs 4 and 5. A simple statistical analysis of the results showed that they were significant.

Regarding the method of mixing, it can be seen from the total figures that folding gave the least leakage, bulking about twice as much, and working about four or five times as much. The greases or mixtures which gave most leakage when pre-worked also tended to give the most leakage when bulked and folded. Mixtures B and D, and C and D, were exceptions to this.

TABLE II

Leakage Results—First Programme

Method of mixing	Bulked	Bulked	Folded	Folded	Worked	Worked
Original Grease A (sodium base)	Pass 2·8	Pass 2·9	Pass 2·4	Pass 1·0	Fail 12·4	Fail 28·7
Specification Grease B (lithium base)	Pass 1·0	Pass 0·8	Pass 1·1	Pass 0·9	Pass 2·3	Pass 2·4
Specification Grease C (sodium base)	Pass 6·9	Pass 6·5	Pass 3·9	Pass 3·0	Pass 3·9	Pass 2·8
Specification Grease D (sodium base)	Pass 1·7	Pass 2·2	Pass 2·0	Pass 2·5	Pass 3·4	Pass 4·1
Mixture of A and B	Pass 4·6	Pass 4·2	Pass 1·5	Pass 3·6	Fail 21·5	Fail 26·3
Mixture of A and C	Pass 6·4	Pass 5·9	Pass 2·9	Pass 2·3	Pass 6·6	Pass 9·2
Mixture of A and D	Pass 7·0	Pass 3·6	Pass 1·5	Pass 3·4	Fail 26·9	Fail 22·7
Mixture of B and C	Pass 3·5	Pass 3·7	Pass 3·3	Pass 2·8	Fail 13·6	Fail 11·8
Mixture of B and D	Pass 1·5	Pass 2·9	Pass 1·3	Pass 1·4	Pass 1·3	Pass 1·7
Mixture of C and D	Pass 3·2	Pass 7·7	Pass 1·3	Pass 1·3	Pass 1·1	Pass 0·5
Total	79·0		43·4		203·2	

The fact that all the greases were assessed as " pass " when bulked or folded was merely because the arbitrary 10 g leakage limit happened to exceed the leakages obtained. When the more stringent pre-working test was carried out, four greases or mixtures thereof were assessed as " fail " because the leakage obtained exceeded this arbitrary figure. It follows that the severity of the test was affected by the initial treatment of the grease. The severity could also be changed by altering the arbitrary 10 g leakage limit, but this is considered less desirable, since the pre-working technique bears some relation to practice in that it simulates to some degree the working which is inevitable in many service applications.

The consistency results are shown in Table III. The results are given in terms of micro-penetration figures before and after test, and the greases are marked " pass " or " fail " according to the arbitrary 25 micro-units maximum amount of change in consistency in either a negative or positive direction. It can be seen that consistency changes gave no guide as to whether or not the leakage was high. Some greases passed the consistency criterion but gave excessive leakage, while other greases failed the consistency criterion but did not give excessive leakage.

TABLE III

Consistency Results—First Programme

Method of mixing	Bulked	Bulked	Folded	Folded	Worked	Worked
Original Grease A	(*a*)	Pass 39/44	Pass 34/36	Pass 34/47	(*b*)	Fail 156/80
Specification Grease B	(*a*)	Pass 84/84	Pass 82/82	Pass 82/92	Pass 100/94	Pass 98/92
Specification Grease C	(*a*)	Pass 63/63	Pass 89/68	Pass 89/65	Fail 128/86	Fail 129/82
Specification Grease D	(*a*)	Pass 73/77	Pass 55/71	Pass 55/77	Pass 105/90	Pass 104/81
Mixture of A and B	Pass 71/77	Pass 71/60	Borderline Fail 53/78	Borderline Fail 53/80	(*b*)	Pass 136/125
Mixture of A and C	Pass 63/43	Pass 63/47	Borderline Pass 41/66	Pass 41/64	Fail 127/66	Fail 133/63
Mixture of A and D	Pass 52/44	Pass 65/53	Pass 48/62	Pass 48/69	Fail 155/89	Fail 144/86
Mixture of B and C	Borderline Fail+ 84/58	Borderline Fail 84/58	Pass 86/86	Pass 86/85	Pass 131/126	Pass 126/108
Mixture of B and D	Pass 80/81	Pass 80/77	Pass 69/75	Pass 69/77	Fail 95/69	Borderline Pass 90/66
Mixture of C and D	Pass 75/63	Pass 75/56	Pass 67/83	Pass 67/77	Fail 88/52	Fail 105/41

Notes.—(*a*) Not done because micro-penetration equipment not available.
(*b*) Inadvertently not done.

Accordingly, for further work the pre-working technique was adopted, but the original 10 g leakage limit was adhered to. Consistency measurements were abandoned.

In the second programme, four greases E, F, G, and H were tested. Grease E was a sodium-lithium base, Grease F was a sodium base, Grease G a sodium–calcium base, and Grease H a sodium-base grease similar, but of a different production, to Grease A in the first programme. The results are given in Table IV.

TABLE IV

Leakage Results—Second Programme

Grease	Leakage and flow, g	
Grease E (sodium–lithium base)	2·6	Pass
Grease F (sodium base)	3·0	Pass
Grease G (sodium–calcium base)	0·8	Pass
Grease H (sodium base)	32·2	Fail
Mixture of E and F	25·2	Fail
Mixture of E and G	6·2	Pass
Mixture of E and H	3·7	Pass
Mixture of F and G	0·4	Pass
Mixture of F and H	5·3	Pass
Mixture of G and H	0·7	Pass

In no case was there any deposit or discoloration, but in two cases, Grease H neat and the mixture of

Greases E and F, the leakage was excessive. The result obtained on Grease H was similar to that obtained previously on Grease A.

In the third programme two further greases I and J were tested, together with the grease H used in the previous programme. Grease I was a calcium-base grease and Grease J was a sodium-base grease. The results are given in Table V.

TABLE V

Leakage Results—Third Programme

Grease	Leakage and flow, g	
Grease H (sodium base) . .	20·1	Fail
Grease I (calcium base) . . .	9·2	Borderline Pass
Grease J (sodium base) . . .	0·9	Pass
Mixture of H and I . . .	31·9	Fail
Mixture of H and J . . .	30·9	Fail
Mixture of I and J . . .	6·0	Pass

Again, in no case was there any deposit or discoloration. As before, Grease H failed because of excessive leakage, and both mixtures incorporating it also failed.

DISCUSSION

It can be seen from the repeat results in the first programme, and from the tests on Grease H in the second and third programmes, that the test method is capable of detecting incompatibility in a repeatable manner.

While it may be considered that the bearing application is unorthodox in that the outer race rotates rather than the inner, the multitude of tests required in order to conduct any investigation of incompatibility problems renders it essential to use a short test. The ASTM Wheel Bearing Grease Tester is, so far as is known, the only bearing test of such a short duration. It has the added advantage of being already standardized as a test method, and the repeatability and reproducibility have been demonstrated to be good. This has been confirmed by the results of the work discussed here.

It is, of course, impossible to state definitely whether or not the degree of incompatibility found would give trouble in service, since the design of bearings and bearing housing vary and since they may or may not be full of grease. It is, however, considered valid to state that greases which fail the test would be most prone to give trouble in service.

It can be seen that although greases A and H failed, mixtures containing them did not invariably fail since the mixtures of greases A and C, E and H, F and H, and G and H were satisfactory.

On the other hand, the fact that the greases individually pass the test very easily does not necessarily mean that the mixture will be satisfactory, since the mixture of greases B and C, and of E and F failed.

It might be expected that greases having soaps of different bases would be most prone to exhibit incompatibility. However, if incompatibility was solely a question of soaps of different bases failing, then it would be expected that the only lithium-based grease out of the four in the first programme would fail every time that it was incorporated into a mixture. This was not always so, since the mixture of greases B and D was satisfactory. Also, the calcium-base Grease I was compatible with the sodium-base grease J in the third programme.

All in all, it is apparent that incompatibility of greases can occur in an apparent haphazard manner. Further study is required to elucidate the reasons for the occurrence of incompatibility. Such variables as the origin of the fats used in the various formulations and the identity of the oil used may be likely avenues for investigation in this respect.

CONCLUSIONS

(1) The repeatability of leakage and flow results from the A.O.L. ASTM Wheel Bearing Test Rig was found to be reasonably good in confirmation of the data given in the ASTM method.

(2) The mixing of some greases was confirmed to have a considerable effect on their performance in the Wheel Bearing Rig; *i.e.* the Rig demonstrated the " incompatibility " of some greases.

(3) The method of mixing the greases, when testing for compatibility, was found to be important. Folding gave least leakage, bulking twice as much as folding, and working four or five times as much.

(4) The method of mixing whereby the grease is worked in a grease worker is preferred to the others, because it is most likely to give uniform treatment to the greases and also because it appears to be more representative of service conditions such as occur shortly after repacking a bearing.

(5) The occurrence of incompatibility of greases tested on the Wheel Bearing Rig was found to be unrelated either to unsatisfactory performance of one of the components forming the mixture or to mixtures of greases containing soaps of different bases.

(6) Changes in penetration of the greases were confirmed not to afford a reliable indication of incompatibility.

ACKNOWLEDGMENTS

Thanks are due to the Admiralty for permission to publish this paper, and to the Chief Scientist of the Admiralty Oil Laboratory, E. J. Widdowson, for his encouragement and help.

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RESOLUTION IN GAS–LIQUID CHROMATOGRAPHY *

By D. BRENNAN † and C. KEMBALL ‡

SUMMARY

Some factors influencing the resolution achieved in gas–liquid chromatography have been studied; particular attention has been paid to the importance of the pressure and the length of column employed.

INTRODUCTION

WHILE much work has been done on the efficiency of liquid phase chromatography, relatively little attention has been given, as yet, to fundamental experimental work on the efficiency of gas phase chromatography. The choice of operating conditions is still largely a matter of experience and trial and error. The present work was undertaken in an effort to throw more light on the various factors which affect the resolution and, at the same time, to provide accurate experimental data relating to carefully controlled separations so that theoretical studies may be the more readily checked.

EXPERIMENTAL

The column consisted of a train of U-tubes of approximately 0·5 cm bore and 30-cm limbs. The tubes were clipped together and connected by short lengths of rubber tubing. This arrangement allowed the column length to be varied with convenience over a wide range. The column sections were immersed in a thermostat maintained at a temperature of 30°. The column packing consisted of dinonyl phthalate supported on "Celite," which was prepared in the manner described by James and Martin,[1] except that the period allowed for sedimentation was 2 minutes and not the 3 recommended, so that the column packing prepared finally was rather more porous than that obtained by these authors. The fractionated "Celite" was added to a solution of the dinonyl phthalate in 40°–60° petroleum ether, which was then removed by evaporation. The column packing contained 0·450 g of dinonyl phthalate per g of "Celite"; the columns were packed uniformly by vibration to a density of 0·463 g/ml. The pressure at the inlet to the column was controlled with an Edwards V.P.C. 1 unit and the flow rate with a needle valve (Edwards Type LB2) placed between the pump and the exit from the column. The pressures at each end of the column were measured with mercury manometers. The rates of flow of the hydrogen carrier gas were measured by means of a capillary flow meter at the inlet to the column and checked against a soap bubble flow meter at the exhaust from the pump. The katharometer detector used was similar in design to that previously described by the authors;[2] the off-balance bridge voltage was recorded on a Honeywell–Brown instrument. Samples, consisting of equal parts by volume of *iso*pentane and diethyl ether, were brought on to the column by explosive evaporation in the carrier gas at a point as near as possible to the beginning of the column.[3]

RESULTS AND DISCUSSION

Theoretical Expressions

Van Deemter, Zuiderweg, and Klinkenberg [4] have discussed the influence of both diffusion and non-equilibrium effects on band broadening in gas–liquid chromatography. They derive an expression of the form:

$$H = A + B/u + Cu \quad . \quad . \quad . \quad (1)$$

where H is the height equivalent to a theoretical plate (H.E.T.P.); A is a constant determined by eddy diffusion resulting from the tortuosity of the channels in the column packing; B is a constant determined by molecular diffusion; C is a constant determined by resistance to mass transfer; and u is the linear velocity of the carrier gas. This equation has been the subject of study by Keulemans and Kwantes,[5] whose findings indicated that the relation was of value in describing chromatographic behaviour. These authors worked with substantially constant mean pressures and with a column of fixed length. In order to test the equation further, the present authors have used a wide range of pressures and column lengths.

Since the diffusion coefficient is proportional to the reciprocal of the pressure, we expect to be able to write

$$B = b \, . \, \overline{P^{-1}} \quad . \quad . \quad . \quad . \quad (2)$$

where b is a constant and $\overline{P^{-1}}$ is the time average of

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the reciprocal of the pressure along the column, given by $\overline{P^{-1}} = \dfrac{\int_0^t P^{-1}\,dt}{\int_0^t dt}$. Using relationships derived by James and Martin,[1] it can be shown that

$$\overline{P^{-1}} = \frac{3}{2} \cdot \frac{1}{P_o} \cdot \frac{r^2 - 1}{r^3 - 1} \quad . \quad . \quad . \quad (3)$$

In equation (3) $r = P_i/P_o$, P_i and P_o are the pressures at the inlet and the outlet ends of the column respectively. Because the fraction of the mean cross-sectional area of the column which is available for the passage of carrier gas is unknown, it is necessary to express the linear velocity of the carrier gas at any point in the form

$$u = kF/a = kFL/V \quad . \quad . \quad . \quad (4)$$

where F is the volume flow rate at that point; L, V, and a are the length, volume, and mean cross-sectional area of the column respectively; k is an unknown constant. As in the case of pressure, the velocity of the carrier gas changes continuously with passage along the column. For the purpose of testing equation (1) it is necessary, therefore, to use the time average of the linear gas velocity. By a treatment similar to that used in the derivation of equation (3) this can be shown to be

$$\bar{u} = \frac{3}{2} \cdot \frac{krF_i}{a} \cdot \frac{r^2 - 1}{r^3 - 1} \quad . \quad . \quad . \quad (5)$$

where F_i is the volume flow rate at the inlet to the column.

For the purpose of calculating the H.E.T.P., the following simplified expression is used:

$$H = 0{\cdot}25L(\delta/t)^2 \quad . \quad . \quad . \quad . \quad (6)$$

where δ is the width of the elution band at half its height and t is the retention time measured from the centre of the peak and corrected for the dead volume. This expression is the same as that used by van Deemter *et al*[4] if it is assumed that the peaks are symmetrical triangles; this form of expression is also supported by the theoretical treatments of James and Martin[1] and of Glueckauf.[6] In order to test equation (1) it is rewritten either as

$$H\left(\frac{k}{\bar{u}}\right) = A\left(\frac{k}{\bar{u}}\right) + \frac{b \cdot \overline{P^{-1}}}{k} \cdot \left(\frac{k}{\bar{u}}\right)^2 + Ck \quad . \quad (7)$$

or

$$H\left(\frac{\bar{u}}{k}\right) = A\left(\frac{\bar{u}}{k}\right) + \frac{b \cdot \overline{P^{-1}}}{k} + Ck\left(\frac{\bar{u}}{k}\right)^2 \quad . \quad (8)$$

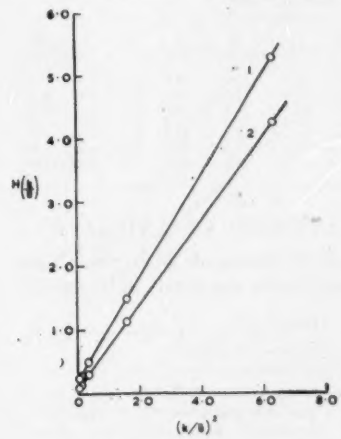

FIG 1

VARIATION OF LINEAR VELOCITY OF CARRIER GAS

L = 136 cm; $\bar{P}$ = 70·2 cm of Hg.

1. *iso*Pentane. 2. Diethyl ether.

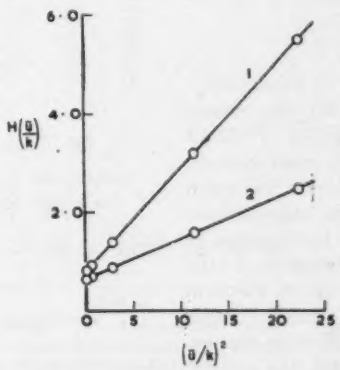

FIG 2

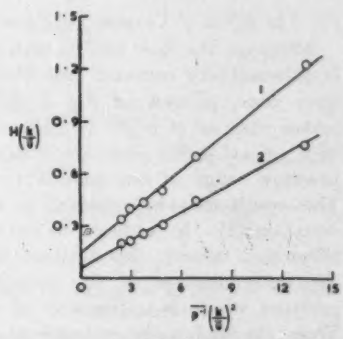

FIG 3

VARIATION OF PRESSURE

L = 136 cm.

1. *iso*Pentane. 2. Diethyl ether.

(1) EXPERIMENTS WITH A COLUMN OF CONSTANT LENGTH

(a) *The Effect of Varying the Flow Rate at Constant Pressure*

The plots in Figs 1 and 2 are derived from the experimental data presented in Table I; the units of the parameters plotted in these and subsequent figures are based on H measured in cm and $\bar{u}$ in cm sec^{-1}. The good linearity obtained for plots of $Hk/\bar{u}$ *v.* $(k/\bar{u})^2$ (*cf.* equation (7)), and of $H\bar{u}/k$ *v.* $(\bar{u}/k)^2$ (*cf.* equation (8)) over a tenfold variation of $\bar{u}/k$ indicates that the eddy diffusion factor A is

TABLE I

Variation of Carrier Gas Flow Rate at Constant Mean Pressure.
$L = 136$ *cm*; $a = 0{\cdot}177$ cm^2; *sample* $= 10\ \mu l$

P_i (cm of Hg)	P_o	F_i (ml/min)	t_1 (minutes)	t_2	δ_1 (minutes)	δ_2
71·1	68·5	4·06	39·38	81·18	9·75	17·98
73·4	67·9	8·10	19·58	40·30	3·65	6·55
75·4	64·7	16·9	9·30	18·75	1·48	2·33
80·5	59·5	31·5	4·75	9·60	0·80	1·13
85·7	55·2	42·0	3·38	6·80	0·62	0·84

In this and the other tables, subscripts 1 and 2 refer to *iso*-pentane and diethyl ether respectively.

relatively unimportant, at least for this type of column. This conclusion is confirmed by further plots presented below.

(b) *The Effect of Varying the Pressure*

Although the flow rate in this set of experiments is substantially constant (see Table II), the results have been plotted in Fig 3 as $Hk/\bar{u}$ *v.* $\overline{P^{-1}}(k/\bar{u})^2$ rather than as H *v.* $\overline{P^{-1}}$ to allow for a small increase in $\bar{u}$. Good linear plots are obtained over the mean pressure range of one-quarter to two atmospheres. This result may be regarded as the justification of equation (2). In addition to its contribution to the theoretical aspect, this relation will be of value in the determination of the optimum mean column pressure which is a function of conflicting factors. Thus, the higher the pressure at which the column is operated, the smaller the value of H and the better the resolution, although it should be noted that the biggest gain in resolution accruing from increased pressure comes at pressures less than one atmosphere, because at higher pressures the contribution of the second term on the right-hand side of equations (7) or (8) becomes relatively less important. On the

TABLE II

Variation of Mean Pressure. $L = 136$ *cm*; $a = 0{\cdot}177$ cm^2; *sample* $= 10\ \mu l$

P_i (cm of Hg)	P_o	F_i (ml/min)	t_1 (minutes)	t_2	δ_1 (minutes)	δ_2
150·1	139·6	17·3	9·81	19·8	1·28	2·00
127·8	117·3	16·9	9·80	19·7	1·38	2·03
100·5	90·0	16·8	9·77	19·6	1·43	2·20
75·4	64·8	16·9	9·30	18·8	1·48	2·33
51·7	40·9	16·9	8·40	17·4	1·60	2·65
25·1	13·5	16·3	7·00	15·0	1·85	3·13

other hand, low column pressures can be advantageous, *e.g.* when it is desired to trap out the eluted fractions as they leave the column, or to increase the response of the katharometer.

(2) EXPERIMENTS WITH VARYING COLUMN LENGTH

For this group of experiments, F_i and r were kept constant so that the value of u at any given fractional distance along the column was independent of the column length. In this way, the effect of pressure on the resolution was studied, and at the same time any disturbance due to increase in column length would have been detected. The experimental results are contained in Table III, and parameters therefrom are plotted in Fig 4. Again linear plots are obtained over the complete range of pressure and of column length, thus confirming the finding of 1 (*b*).

TABLE III

Variation of Column Length at Constant Flow Rate of Carrier Gas

Sample (μl)	L (cm)	a (cm^2)	P_i (cm of Hg)	P_o	F_i (ml/min)	t_1 (minutes)	t_2	δ_1 (minutes)	δ_2
10	136	0·177	22·3	11·3	17·3	6·8	15·0	1·91	3·38
10	205	0·178	34·8	17·3	17·3	10·9	23·0	2·07	3·51
15	273	0·177	49·0	24·2	17·4	14·9	30·5	2·17	3·51
20	341	0·177	61·1	30·4	17·3	19·4	39·3	2·42	3·82
25	480	0·178	89·5	44·6	17·3	27·3	55·0	2·54	3·90
25	615	0·176	115·9	57·5	17·2	34·7	69·7	2·64	4·14
25	753	0·174	146·7	73·3	17·4	41·9	83·9	2·76	4·08

(3) THE QUANTITIES b/k AND kC

Values for b/k and kC obtained from the slopes of the plots discussed above are listed in Table IV.

TABLE IV

The Constants b/k and kC

Conditions	b_1/k (cm of Hg)($cm^2 sec^{-1}$)	b_2/k	kC_1 (sec)	kC_2
1. (*a*) Varying flow rate constant column length . .	56	42	0·226	0·080
(*b*) Varying pressure constant column length . .	79	54	0·142	0·056
2. Varying column length . .	79	54	0·229	0·110

The agreement obtained by the different methods is not uniformly good. While the values of b/k derived from the experiments in which the pressure was varied are in excellent agreement with those obtained from varying column length for both *iso*-pentane and ether, the values determined at a single pressure with varying flow rate are low by a considerable amount. In contrast, it is the kC values derived from the variation of pressure using a short column of constant length which are anomalous. No explanation of this behaviour is offered. Further, while the magnitude of the constants is of the correct order, it is difficult to explain the fact that b_2/k is always much smaller than b_1/k. For a given column, the ratio b_2/b_1 is supposed to be determined solely by the ratio of the molecular diffusion coefficients of the two components.[4] The molecular diffusion coefficients of *iso*pentane and of ether are very similar, hence it would seem that, in spite of the findings presented above, the constant B of equation (1) is determined by more than molecular diffusion. The difference in the values for C_1 and C_2 can be explained

in terms of the difference in the gas–liquid partition coefficients of the two components.

EMPIRICAL RELATIONS

The concept of H.E.T.P. is limited in its applications to practical problems, since the information necessary for its employment is frequently not available. Because of this, relations which express resolution in direct terms and involve only the simplest parameters are of particular value.[7] We define a quantity R such that

$$R = d - (\delta_1 + \delta_2) \quad . \quad . \quad . \quad (9)$$

where d is the separation of the peak maxima of the two components. R is a direct measure of the resolution in that it is approximately the distance between the bases of the two peaks, namely when $R = 0$, the bases of the two peaks just touch and resolution is complete. Negative values of R indicate overlap of the peaks. In Fig 5, which is derived from the data of Table III, it is seen that R bears a good linear relationship to column length, which fact is of value in determining the minimum length of column required to effect a given separation.

It has been recommended [8] that retention volumes should be expressed relative to suitable internal standards, and this is, in general, a desirable procedure. However, caution is required in the employment of such data for accurate work in view of the following further interesting departure from ideality which was observed for real columns. The variation of the ratio $(V^0_R)_2/(V^0_R)_1$ with the mean pressure $\bar{P}$ graphed in Fig 6 shows that, in this particular case, the relative retention volume begins to increase significantly below a mean pressure of about 50 cm. This increase in the relative retention volume means that the ratio of the times for the emergence of the band maxima increases, but the effect is more than offset by band broadening consequent upon reduction in pressure; the net result is a decrease in the resolution.

CONCLUSIONS

The equation, proposed by van Deemter, Zuiderweg, and Klinkenberg, for the H.E.T.P. of a column has been tested for different flow rates, pressures, and column lengths and found satisfactory even for columns containing a relatively small number of theoretical plates. The results confirm that the term in the equation attributed to molecular diffusion depends inversely on the pressure. However, markedly different values of this term are obtained for two substances having similar diffusion coefficients.

A simple function defining resolution is proposed which, unlike H.E.T.P., varies linearly with column length and, consequently, may be used to assess the minimum length of column to effect a given separation.

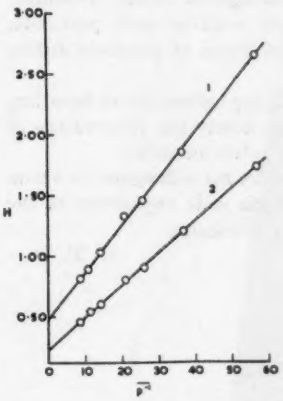

Fig 4

VARIATION OF COLUMN LENGTH AND PRESSURE WITH CONSTANT LINEAR VELOCITY OF CARRIER GAS

1. *iso*Pentane. 2. Diethyl ether.

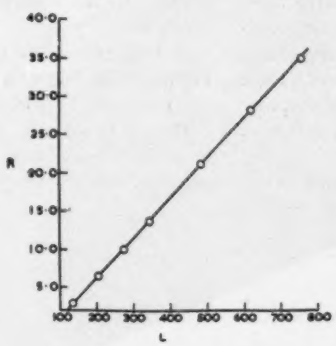

Fig 5

VARIATION OF RESOLUTION WITH COLUMN LENGTH FOR CONSTANT LINEAR VELOCITY OF CARRIER GAS

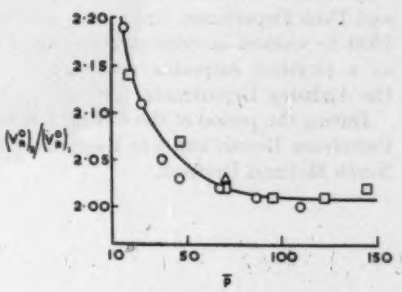

Fig 6

VARIATION OF RELATIVE RETENTION VOLUME WITH PRESSURE

△ Varying flow rate, constant column length.
□ Varying pressure, constant column length.
○ Varying column length, constant flow rate.

A simple function defining resolution is proposed which, unlike H.E.T.P., varies linearly with column length and, consequently, may be used to assess the minimum length of column to effect a given separation.

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OBITUARY

ERIC BRADBURY
1898–1957

ERIC BRADBURY, who died on 15 September 1957, was the Manager of the Dingle Terminal of the Esso Petroleum Co. Ltd.

He joined the Anglo-American Oil Co. Ltd. (as the Company was then known) in May 1925, after completing his apprenticeship as an engineer at the Railway Works at Crewe. He was employed in the Pump and Tank Department until 1928, and from then until 1938 he worked in various Divisions of the Company as a physical inspector and also as a member of the Auditing Department.

During the period of the war he was seconded to the Petroleum Board, and was Regional Engineer for the North Midland Division.

Following this, after a period in the London head office, and also as Divisional Engineer in the Northern Division, he was made manager of Dingle Terminal.

In his various spheres of work he took particular interest in the leakage and losses of products during operations.

Keenly interested in all improvements in handling methods, he followed very closely the proceedings of the Institute, of which an active member.

He will be greatly missed by his colleagues, to whom he always made available his wide experience of the physical side of petroleum marketing.

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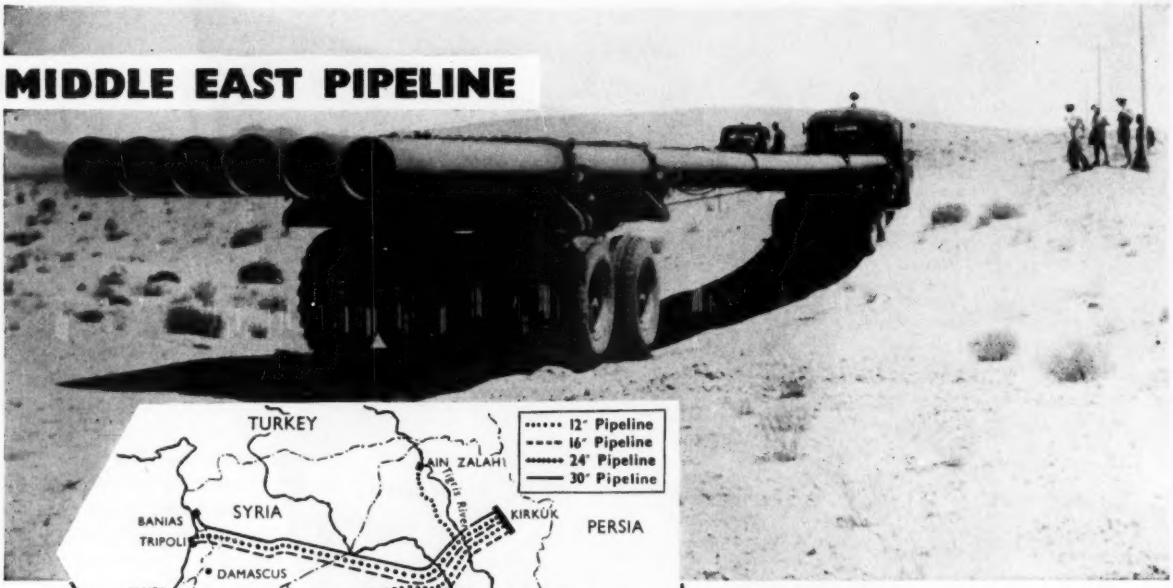

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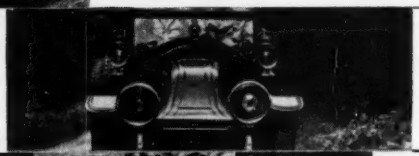
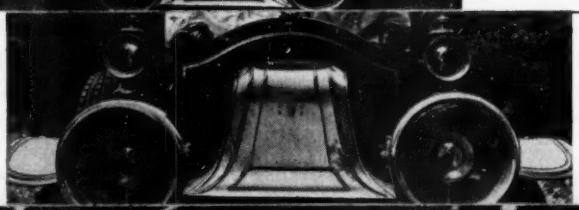
Helpful! Here am I practising for the only real sporting event of the year and all you can talk about is some wretched little gadget on one of your blasted hairyplanes. Can't you see I need to concentrate?

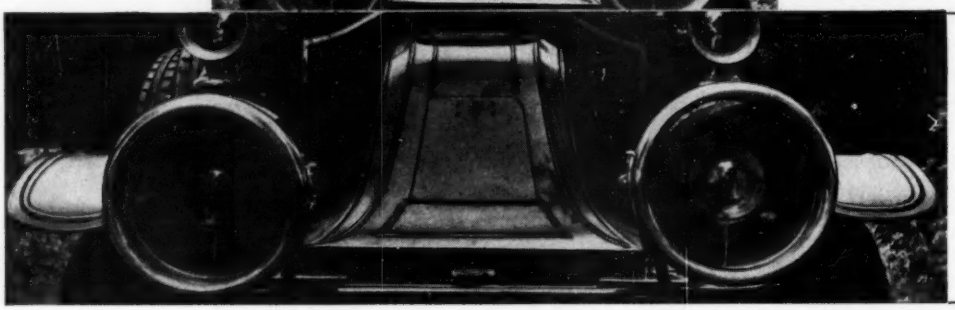


It's not a little gadget and they'd never put it on a plane—it's bigger than this Renault. They put it in the line between the storage and aircraft tanks to make sure the plane gets clean, water-free fuel.

That's the trouble with your infantile modern engines—they have to be fed on strained foods or they get indigestion. Now look at Dotty . . .



Exactly. Do you really think she enjoys having that steam pouring through her exhaust? Now if you took a Simmonds Fram Separator Filter in tow you could have 100% water separation and complete filtration of solids down to 5 microns.



It's tempting, very tempting . . . but it wouldn't be fair on the other competitors. Now d'you mind if we stop a minute . . . I think I really will have to get the rest of that bird's nest out of the tank.

the point of the argument... **FRAM SEPARATOR FILTERS** for clean water-free fuel

For more details of this and other Simmonds products SEND FOR LITERATURE to

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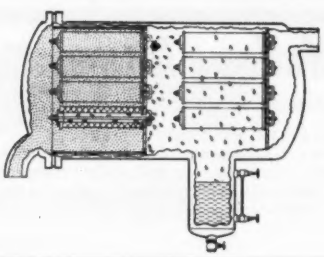

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A tanker installation showing NH Forged Steel Valves in service.

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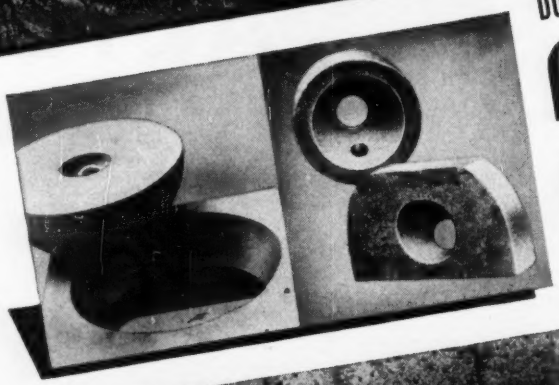
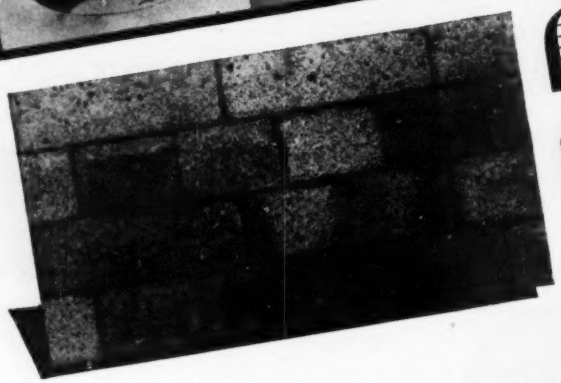


DURAX No 2

REFRACTORY CONCRETE

For casting in situ and making special shapes. Supplied dry. Special characteristics include—rapid setting as hard as firebrick: pours into position: no permanent volume change: little tendency to spall. Maximum service temperature 1300°C.



DURAX No 3

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A finely ground air setting cement for jointing all types of firebricks. Supplied dry. Special characteristics include—produces thin and strong joints: negligible shrinkage: highly refractory: economical in use. Maximum service temperature 1650°C.

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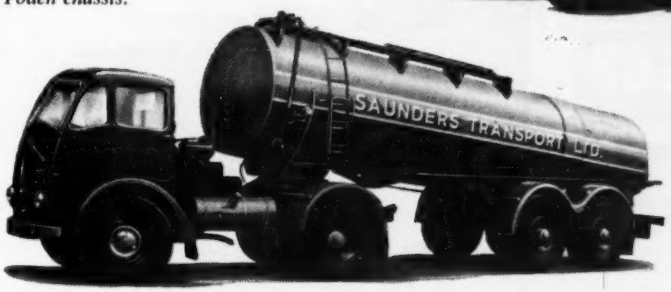
(right) A 2,400 gallon 5-compartment tank mounted on Bedford Tractor and Carrimore running gear.

(below) A 3,300 gallon Mild Steel Articulated Frameless Tank mounted on Foden chassis.



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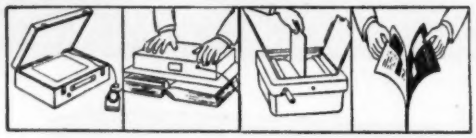

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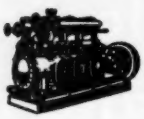

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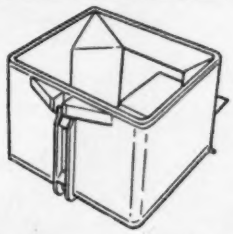
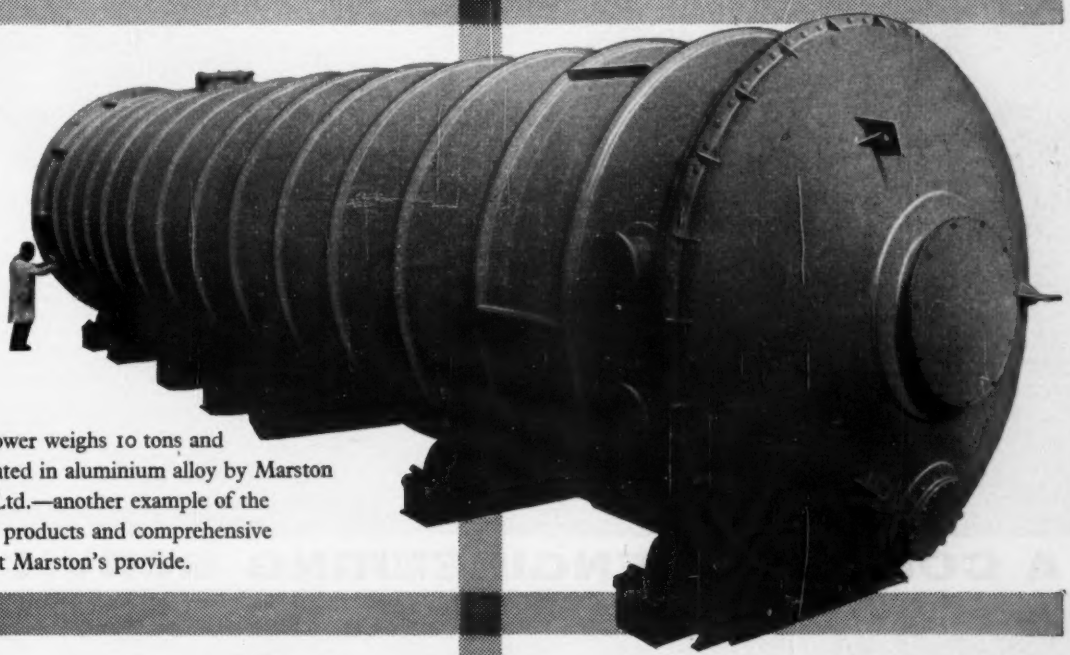
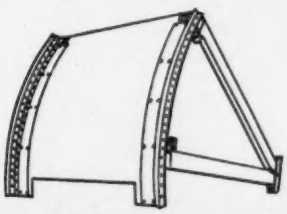


This truck-container is designed to carry granular material of particle size approximately $\frac{1}{16}''$. Special attention had to be paid to the fit of the door and the smooth finish of the interior. The body ($\frac{3}{8}''$ Plate Kynal M 39/2) was welded by the Argon arc and Argonaut processes.



This 52′ tower weighs 10 tons and was fabricated in aluminium alloy by Marston Excelsior Ltd.—another example of the specialised products and comprehensive service that Marston's provide.



This radial sluice-gate is 6′ 6″ wide and 6′ high. It is made of aluminium alloy, to minimise maintenance costs. To obtain a clean design free from any crevices where corrosion might start, the gate was welded by the Argon arc process. It is believed to be one of the first examples in this country of a radial sluice-gate in welded aluminium alloy.

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